

METHOD FOR IMPERMEABILIZING A TUNNEL COVERING FORMED BY
PREFABRICATED ASHLARS AND PREFABRICATED ASHLAR WHICH CAN BE
USED IN SUCH A METHOD

DESCRIPTION

The present invention generally relates to the technical sector of constructing natural tunnels. In particular, the invention relates to a method for impermeabilizing a tunnel covering which is formed by prefabricated ashlar and a prefabricated ashlar which can be used in such a method.

As known, one of the basic operations in constructing natural tunnels by means of excavation underground is the generation of one or more covering layers in order to stabilize and contain the walls which are exposed by the excavation.

A known type of covering for natural tunnels is constituted by prefabricated elements which are made from concrete and which are suitably shaped and placed beside each other and known as "ashlars". This type of covering is typically brought about by sequentially generating, gradually with the advance of the excavation, covering rings which extend over the entire perimeter of the excavation section, each one formed by a plurality of such ashlar.

Typically, but not exclusively, this type of covering is used in natural tunnels which are constructed by means of so-called "mechanized" techniques. In this case, the basic operations of excavation underground, removal of the excavation material and covering the walls of the excavation are carried out continuously and simultaneously by means of large automated machines, which are suitably designed, called TBM (Tunnel Boring Machines). These machines carry out the excavation in an integral and continuous manner and

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simultaneously provide for the removal of the excavation material from the front of the excavation and the positioning of the covering of the tunnel gradually with the advance of the excavation front.

In the case of natural tunnels which are constructed by means of "mechanized" techniques, there is generally provided a single covering layer which is precisely formed by prefabricated ashlar as described above. In this case, the covering of the tunnel has to simultaneously ensure the structural stability of the tunnel and prevent introductions of water inside the tunnel itself. These introductions have to be avoided as far as possible, both for reasons of immediate safety for the traffic through the tunnel and because they cause a premature deterioration of the covering, the restoration of which requires extremely expensive interventions - both in direct terms and in indirect terms, as a result of the limitation or even stoppage of the traffic through the tunnel which are necessary to carry them out - which are difficult to carry out and often also not generally effective or durable. Particularly in the case of coverings which are formed by prefabricated ashlar, the possible introduction of water in the region of the joint lines between adjacent ashlar, particularly if combined with repeated cycles of freezing and thawing, causes cracking and breakages of the concrete over time in the region of the edges of the ashlar.

In order to impermeabilize tunnel coverings which are formed by prefabricated ashlar, it is known to use ashlar which are provided with a water-tight seal which extends along the entire peripheral edge thereof. These are generally water-tight seals which are made from an elastomer material with substantial dimensions, which are capable of withstanding the

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high compression forces, to which they are subjected during use, without becoming damaged and which are provided with an external water-tight face which is typically planar. During the assembly of the ashlar so as to form the ashlar rings, and subsequently the axial juxtaposition of the ashlar rings, the contact pressure between adjacent ashlar pushes one against the other the mutually facing water-tight faces of water-tight seals of adjacent ashlar, typically bringing about a partial deformation of the water-tight seals themselves, in such a manner that, between adjacent ashlar, there are formed sealed joint lines which are impermeable and which prevent the passage of water through the tunnel covering formed in this manner.

In practice, it has been found that the solution described above causes problems in the region of the angles of the ashlar. At these locations, in fact often between the water-tight faces of the water-tight seals of adjacent ashlar, there remain gaps through which water can be introduced, sometimes also in large amounts.

This disadvantage is connected with the type of water-tight seals which are used for these applications and may also occur in spite of the maximum care taken by the operators while carrying out correct positioning of the ashlar. In fact, these water-tight seals, when they are applied continuously in the region of corner zones of the ashlar, are generally subjected to shape modifications, as a result of their substantial dimensions and their structure, so as to prevent excellent contact with facing water-tight faces of water-tight seals of adjacent ashlar. In order to attempt to overcome this disadvantage, there have been developed water-tight seals for ashlar, the corner regions of which are constituted by suitable preformed inserts which are joined to

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the corresponding rectilinear sections of the water-tight seal by adhesive-bonding or vulcanization. In this case, however, while there is a greater control over the maintenance of the geometric shape of the corner region, there are generated in the water-tight seal variations of consistency which can also lead to imperfect contact with facing sealing faces of water-tight seals of adjacent ashlar.

Furthermore, although occurring less frequently, an imperfect contact between facing water-tight faces of water-tight seals of adjacent ashlar with the resultant generation of gaps through which water can be introduced may also occur in the region of rectilinear sections of the joints between the ashlar if the joints have not been positioned completely correctly.

Therefore, it is evident that the technical solutions described above for impermeabilizing tunnel coverings which are formed by prefabricated ashlar are not capable of ensuring with certainty a water-tightness with respect to introductions of water from the surrounding ground to the tunnel. As already mentioned above, repair operations when the covering is completed and the tunnel is in service are, in addition to being expensive, difficult to carry out and have uncertain results, particularly as a result of the difficulty of access and potential introduction locations, the gaps between adjacent ashlar being of a very small width (typically between 5 and 10 mm) and the respective water-tight seals normally being positioned in the vicinity of the extrados of the covering and therefore with a considerable spacing (typically between 300 mm and 1000 mm) from the internal, accessible wall of the covering.

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In light of the above, a main object of the present invention is to provide a method for impermeabilizing a tunnel covering which is formed by prefabricated ashlar and a prefabricated ashlar which can be used in such a method which ensure with certainty the water-tightness of the covering with respect to introductions of water in the region of the joints between the ashlars.

Another object of the present invention is to provide a method for impermeabilizing a tunnel covering which is formed by prefabricated ashlars and a prefabricated ashlar which can be used in this method which can be readily used in the scope of any known methodology for constructing natural tunnels which provides for the generation of a covering which is formed by prefabricated ashlars, particularly in the context of methodologies based on a "mechanized" technique using TBM.

According to the present invention, these objects are achieved by means of a method for impermeabilizing a tunnel covering which is formed by prefabricated ashlars comprising the steps set out in the appended claim 1, and by means of a prefabricated ashlar for use in such a method according to the appended claim 9.

In particular, in a first aspect thereof, the invention relates to a method for impermeabilizing a tunnel covering which is formed by prefabricated ashlars, comprising the steps of:

a) providing a plurality of prefabricated ashlars, wherein each prefabricated ashlar comprises an intrados face, an opposite extrados face with respect to the intrados face, a peripheral edge which connects the intrados face and the extrados face and a peripheral groove which extends longitudinally in a continuous manner along the peripheral

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edge, and wherein at least some prefabricated ashlar further comprise at least one injection pipe having a first end opening in the region of the intrados face and at least one second end opening in the region of the peripheral groove;

b) positioning the plurality of prefabricated ashlars along walls of a tunnel so as to form a tunnel covering, wherein the tunnel covering comprises a grid of interconnected joint lines, each one being defined between two respective, mutually adjacent prefabricated ashlars, wherein in the region of each joint line corresponding sections of the peripheral grooves of the two mutually adjacent prefabricated ashlars are mutually facing so as to form a respective hollow channel, with which there is formed in the tunnel covering a grid of interconnected hollow channels corresponding to the grid of interconnected joint lines, and

c) filling the grid of interconnected hollow channels with a sealing material which is impermeable to water and which can be injected, wherein the sealing material is injected into the grid of interconnected hollow channels through the first end opening of the at least one injection pipe of one or more of the prefabricated ashlars which are provided with at least one injection pipe.

According to this method, the impermeabilization of a tunnel covering which is formed by prefabricated ashlars is advantageously obtained by providing, in the region of the joint lines between the ashlars, suitable interconnected hollow channels so as to form a continuous grid corresponding to the grid of the interconnected joint lines and by injecting into such hollow channels a suitable sealing material until completely filling the grid which is formed by the channels. Once consolidated and the final conditions for use have been achieved, the sealing material which has been injected forms in the tunnel covering a continuous sealing

strand which is monolithic and which extends along the entire grid of the joint lines between the ashlar. This sealing strand ensures a specific water-tightness of the tunnel covering with respect to introductions of water in the region of the joints between the ashlars, particularly avoiding the incidence of problems which are connected with poor contact between water-tight seals of the prefabricated ashlars, as previously discussed with reference to the prior art.

Furthermore, the impermeabilization method of the invention can readily be carried out in the context of any known methodology for constructing natural tunnels with a covering which is formed by prefabricated ashlars, particularly but not exclusively in the context of the methodologies based on a "mechanized" technique using TBM without any need for modifications to the respective operating steps and/or the sequence thereof. In fact, on the one hand, the grid of interconnected hollow channels which is intended to receive the sealing material is automatically formed during the action of positioning the ashlars in order to construct the covering of the tunnel, on the other hand, the injection of the sealing material can be carried out readily and in a controlled manner once the covering has been completely constructed, through the injection pipes which are suitably arranged in the ashlars and which are directly accessible from the intrados side of the covering itself.

According to a preferred embodiment of the method, each prefabricated ashlar further comprises a peripheral water-tight seal which extends along the respective peripheral edge and which has a water-tight face, that is to say, side, which is intended to come into contact with corresponding water-tight faces, that is to say, sides, of peripheral water-tight seals of adjacent prefabricated ashlars in a tunnel covering,

and the peripheral groove is formed in the water-tight face of the water-tight seal.

In this manner, the sealing action of the water-tight seals of the ashlar, which is typical of solutions of the prior art, is advantageously combined with the sealing action of the sealing material which is injected into the grid of interconnected hollow channels, which are formed in the tunnel covering in the region of the joint lines between the ashlar, as described above, and are in this case delimited by the mutually facing water-tight seals of adjacent ashlar. In particular, the sealing material is capable of ensuring the water-tightness even where the mutually facing water-tight faces of water-tight seals of adjacent ashlar are not completely in contact with each other and where therefore introductions of water can occur.

In this embodiment of the method, the step c) of filling the grid of interconnected hollow channels by injecting the sealing material can be carried out during the construction of the tunnel, before it is brought into use, for example, immediately after the covering has been positioned, or also at a later time after the tunnel is brought into use if introductions of water between the water-tight seals of the ashlar appear.

In a variant of this embodiment, the peripheral groove may comprise a diaphragm which delimits a closed chamber which extends longitudinally inside the peripheral groove and which comprises the at least one second end opening of the at least one injection pipe and, in the step c) of filling the grid of interconnected hollow channels with the sealing material, the injection of the sealing material brings about an eversion of the diaphragm outside the peripheral groove and inside the

peripheral groove facing it of an adjacent prefabricated ashlar.

Advantageously, following the eversion, the diaphragm forms, inside the corresponding channel which is formed by the two mutually facing peripheral grooves, a containment bag for the injected sealing material, providing a water-tightness with respect to losses of sealing material in the region of the interfaces between the water-tight seals which are in mutual contact and which could appear in the case of imprecise alignment of the water-tight seals in the radial direction of the tunnel covering.

According to an alternative embodiment of the method of the invention, the prefabricated ashlars may not have a peripheral water-tight seal and the peripheral groove may be formed directly, that is to say, in one piece, in the ashlars themselves, in the region of the respective peripheral edge. In this case, the water-tightness of the tunnel covering with respect to introductions of water in the region of the joints between ashlars is ensured only, but in any case in a certain and reliable manner, by the sealing material with which the above-mentioned grid of interconnected hollow channels is filled and which therefore has to be injected already during the construction of the tunnel.

In a variant of this alternative embodiment, at least some prefabricated ashlars may comprise a peripheral tubular element which is made from elastomer material and which is received in the respective peripheral groove and the at least one second end opening of the respective at least one injection pipe opens into this tubular element. In the step c) of filling the grid of interconnected hollow channels with the sealing material, the sealing material is injected inside

the tubular element, bringing about the expansion thereof in the hollow channels which are formed by the peripheral groove of the ashlar in question and by the corresponding peripheral grooves which face it of adjacent prefabricated ashlars.

In this case, the tubular element also forms, inside the hollow channels involved, a containment bag for the sealing material injected, providing a water-tightness with respect to losses of sealing material in the region of the joint lines between adjacent prefabricated ashlars which could appear in the case of adjacent prefabricated ashlars in the radial direction of the tunnel covering.

Preferably, the step c) of filling the grid of interconnected hollow channels with the sealing material comprises:

- c1) injecting the sealing material through an injection pipe of one of the prefabricated ashlars which are provided with at least one injection pipe until the injection pressure reaches a maximum predetermined value;
- c2) interrupting the injection;
- c3) defining a propagation area of the sealing material, in which the sealing material which is injected has filled a corresponding portion of the grid of interconnected hollow channels, verifying which injection pipes which surround the injection pipe which is previously used have been at least partially filled with the injected sealing material;
- c4) resuming the injection of the sealing material in the region of another injection pipe of one of the prefabricated ashlars which are provided with at least one injection pipe which is located outside previously defined propagation areas of sealing material;
- c5) repeating the steps from c1) to c4) for the entire extent of the tunnel covering.

In this manner, the filling of the grid of interconnected hollow channels is carried out successively for zones until covering the entire extent of the tunnel covering. Advantageously, this allows the injection to be carried out at relatively low pressures and also better control of the propagation of the sealing material injected into the grid of interconnected hollow channels. The extent of the propagation area of the sealing material introduced in each injection step can be readily evaluated by means of a visual inspection of the injection pipes surrounding the injection pipe which is used, in order to define the ones which have been at least partially filled by the injected sealing material.

Preferably, the step b) of positioning the prefabricated ashlar comprises arranging the prefabricated ashlars so as to form a plurality of rings of prefabricated ashlars which are beside each other in a longitudinal direction of the tunnel, wherein each ring of ashlars is angularly staggered in a circumferential direction of the tunnel with respect to the adjacent rings, as a result of which the grid of interconnected joint lines and the grid of interconnected hollow channels comprise a plurality of continuous circumferential rings which are connected by a plurality of longitudinal rectilinear sections which, at least in adjacent rings of prefabricated ashlars, are angularly staggered relative to each other in the circumferential direction of the tunnel.

Preferably, the sealing material which is impermeable to water and which can be injected is a synthetic resin, preferably a polyurethane resin or a silicone resin, having a high modulus of elasticity after polymerization.

In a second aspect thereof, the invention relates to a prefabricated ashlar for a tunnel covering which can be used in the above-described method, comprising an intrados face, an opposite extrados face with respect to the intrados face, a peripheral edge which connects the intrados face and the extrados face, a peripheral groove which extends longitudinally and continuously along the peripheral edge and at least one injection pipe having a first end opening in the region of the intrados face and at least one second end opening in the region of the peripheral groove.

Prefabricated ashlars having the above-mentioned features allow the same advantages set out above to be afforded with reference to the first aspect of the invention. In particular, by means of the juxtapositioning of these ashlars during the construction of a tunnel covering, there is automatically generated a grid of interconnected hollow channels corresponding to the grid of the joint lines formed between adjacent ashlars, which can then be filled with a sealing material which is impermeable to water and which can be injected in order to make the tunnel covering water-tight or impermeable with respect to introductions of water in the region of the joints between the ashlars. The injection of the sealing material can be carried out readily and in a controlled manner through the injection pipes which are suitably arranged in the ashlars and which are directly accessible from the intrados side of the tunnel covering.

Preferably, the prefabricated ashlar comprises at least one injection pipe for each side of the individual peripheral edge. Advantageously, the number of injection pipes in the region of each side of the peripheral edge can be proportional to the length of the side so that longer sides

are provided with a greater number of injection pipes with respect to shorter sides.

According to a preferred embodiment, the prefabricated ashlar further comprises a peripheral water-tight seal which extends along the peripheral edge and which has a water-tight face, or side, which is intended to come into contact with corresponding water-tight faces, or sides, of peripheral water-tight seals of adjacent prefabricated ashlars in a tunnel covering, and the peripheral groove is formed in the water-tight face of the peripheral water-tight seal.

In a variant of this embodiment, the peripheral groove can be provided with a diaphragm which delimits a closed chamber which extends longitudinally in the groove itself and which comprises the at least one second end opening of the at least one injection pipe of the prefabricated ashlar.

According to an alternative embodiment, the prefabricated ashlar does not have a peripheral water-tight seal and the peripheral groove is formed directly, that is to say, in one piece with, in the peripheral edge of the prefabricated ashlar.

In a variant of this embodiment, the prefabricated ashlar may further comprise a peripheral tubular element which is made from elastomer material and which is received in the peripheral groove and the at least one second end opening of the at least one injection pipe can open into the tubular element.

The peripheral groove may generally have any suitable cross-sectional shape which comprises rectilinear and/or curvilinear sections.

The invention further also relates to a tunnel comprising a covering which is constructed by means of prefabricated ashlar, wherein the covering is made impermeable by means of the above-described method.

Additional features and advantages of the invention will be better appreciated from the following detailed description of preferred embodiments thereof, set out below, by way of non-limiting example, with reference to the appended drawings, in which:

- Figure 1 is a perspective, schematic, longitudinally sectioned view of a portion of a tunnel comprising a covering which is formed by prefabricated ashlar according to the invention and which is made impermeable by means of the method according to the invention;
- Figure 2 is a perspective, schematic view of an embodiment of a prefabricated ashlar according to the invention;
- Figure 2a is an enlarged view of the detail D1 of Figure 2;
- Figure 2b is a sectioned view of the prefabricated ashlar of Figure 2 along the line II-II of Figure 2;
- Figure 2c is an enlarged view of the detail D2 of Figure 2b;
- Figure 3 is a perspective, schematic view of another embodiment of a prefabricated ashlar according to the invention;
- Figure 3a is a sectioned view of the prefabricated ashlar of Figure 3 along the line III-III of Figure 3;
- Figure 3b is an enlarged view of the detail D3 of Figure 3a;
- Figure 4 is a perspective, schematic view of two rings of prefabricated ashlar of the covering of the tunnel of Figure 1;

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- Figure 5 is a perspective, schematic view, partially sectioned, of two prefabricated ashlar according to the embodiment of Figure 2, which are mutually adjacent;
- Figure 6 is a perspective, schematic view, partially sectioned, of four prefabricated ashlar according to the embodiment of Figure 3, which are mutually adjacent;
- Figure 7 is a projection into a plane of a portion of the covering of the tunnel of Figure 1, when viewed from the intrados side;
- Figure 8 is a schematic, cross-sectioned view of the covering of the tunnel of Figure 1 in the region of the line VIII-VIII of Figure 7;
- Figure 9 is a schematic, cross-sectioned view of the covering of the tunnel of Figure 1 in the region of the line IX-IX of Figure 7;
- Figure 10 is a perspective, schematic view, developed in a plane, of a portion of the grid of interconnected hollow channels which is formed in the covering of the tunnel of Figure 1 following the mutual juxtaposition of the prefabricated ashlar of Figure 2;
- Figures 11a-c are schematic, cross-sectioned views similar to the view of Figure 9 which illustrate steps of filling a hollow channel which is formed in the region of the joint between two adjacent prefabricated ashlar in the covering of the tunnel of Figure 1 with an injectable sealing material;
- Figure 12 is a schematic, cross-sectioned view similar to the view of Figure 9, wherein the prefabricated ashlar on the left constitutes an alternative embodiment of the prefabricated ashlar of Figure 2, and
- Figure 13 is a schematic, cross-sectioned view of the covering of the tunnel of Figure 1, still in the region of the line IX-IX of Figure 7, wherein the right ashlar corresponds to the embodiment of the prefabricated ashlar of

Figure 3 and the left ashlar constitutes a variant of the same prefabricated ashlar.

Figure 1 shows a portion of a tunnel 100 comprising a covering 110 which is formed by a plurality of prefabricated ashlars 1 according to the present invention. In a manner known per se, the ashlars 1 are configured as ring segments and are installed in the covering 110 so as to form a plurality of closed rings 111 of circular shape, which are mutually adjacent in the longitudinal development direction of the tunnel 100. Figure 4 shows separately two of these rings 111 which are formed by the ashlars 1.

A preferred embodiment of the ashlars 1 forming the covering 110 of the tunnel 100 is shown in greater detail in Figures 2 and 2a-c.

Each ashlar 1 is constituted by a prefabricated element which is made from reinforced concrete and which has a rectangular or trapezoidal peripheral shape (in the case of the so-called "key ashlar" and the two ashlars adjacent thereto in each ring 111) and a curvature in one of the two extent directions, particularly the greatest extent direction, corresponding to the curvature of the rings 111. Each ashlar 1 therefore comprises an intrados face which, in the installed condition of the ashlar 1, is directed towards the interior of the tunnel 100, an extrados face 12 (which can be seen in Figure 4) opposite the intrados face 11 and a peripheral edge 13 which connects the intrados face 11 and the extrados face and which is formed by a pair of long sides or faces 131 which are mutually parallel and by a pair of short sides or faces 132 which are mutually parallel or oblique.

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Each ashlar 1 is further provided with a peripheral water-tight seal 2 which extends along the entire peripheral edge 13, preferably near the extrados face 12.

As can better be seen in Figure 2c, the water-tight seal 2 has a water-tight face or side 21 which is directed outwards and is intended to come into contact with corresponding water-tight faces or sides 21 of similar water-tight seals 2 of ashlar 1 adjacent to the ashlar 1 in question when it is installed in the covering 110 of the tunnel 100. In the water-tight face 21 there is formed longitudinally a groove 3 which, similarly to the water-tight seal 2, extends continuously along the entire peripheral edge 13 of the ashlar 1. The presence of the groove 3 defines in the water-tight face 21 two longitudinal water-tight portions 211 which are separated and which are positioned at opposite sides with respect to the groove 3 and also extend continuously along the entire peripheral edge 13 of the ashlar 1 in the region of which the water-tightness is specifically brought about with respect to water-tight seals 2 of adjacent ashlar 1.

In the preferred embodiment shown here, the groove 3 has a cross-section comprising a first portion 31, which is distal with respect to the water-tight face 21 and which constitutes the bottom of the groove 3 with a circular shape and a second portion 32, which is proximal with respect to the water-tight face 21 and open in the region thereof, and which is formed by two rectilinear segments which face and are parallel with each other and which are connected to the ends of the first portion 31 (see also Figure 8).

The groove 3 can generally have any suitable form with a cross-section, comprising rectilinear sections and/or

curvilinear sections, which is technically able to be formed in the water-tight seal 2.

As shown in particular in Figures 2c, 8, 9 and 11a-c, the water-tight seal 2 is preferably provided in the region of a rear side thereof opposite the water-tight face 21 of a pair of projecting anchoring portions 22 which extend longitudinally along the entire water-tight seal 2, for anchoring it to the ashlar 1. The anchoring portions 22 may have a cross-sectional shape which is, for example, substantially L-shaped. During the production of the ashlar 1, a rear zone of the water-tight seal 2 is surrounded in the casting of concrete and the anchoring portions 22 which are provided in this region ensure a stable and secure connection of the water-tight seal 2 to the body of the ashlar 1.

The water-tight seal 2 is made from a suitable elastomer material, for example, EPDM rubber (Ethylene Propylene Diene Monomer) or silicone rubber having a Shore-A hardness which is preferably between 30 and 90, more preferably between 40 and 60.

Each ashlar 1 further comprises one or more injection pipes 4 which are suitably arranged to allow the injection of a sealing material which can be injected into hollow channels which are formed in the covering 110 in the region of the joint lines between adjacent ashlars 1, as described in greater detail below with reference to a preferred embodiment of the impermeabilization method according to the invention.

Preferably, each ashlar 1 comprises at least one injection pipe 4 for each of the sides 131 and 132 of the peripheral edge 13 thereof, where the long sides 131 can advantageously provide for a number of injection pipes 4 greater than the

number of injection pipes 4 which are provided for the short sides 132. In particular, as can be seen in Figure 2, in the preferred embodiment illustrated here, each ashlar 1 comprises an injection pipe 4 for each short side 132 of the peripheral edge 13 and two injection pipes 4 for each long side 131 of the peripheral edge 13.

The injection pipes 4 preferably all have the same configuration. In particular, as Figure 2c shows, each injection pipe 4 preferably has an L-shape, comprising a first rectilinear section 41 which extends inside the ashlar 1 substantially parallel with the respective side 131 or 132 of the peripheral edge 13, and a second rectilinear section 42 which extends inside the ashlar 1 substantially perpendicularly to the same side 131 or 132 of the peripheral edge 13. The first section 41 opens outside the ashlar 1 in the region of the intrados face 11 by means of a first end opening 410 of the injection pipe 14 and the second section 42 opens in the groove 3 of the water-tight seal 2 by means of a second end opening 420 of the injection pipe 4. The injection pipe 4 therefore places in fluid communication the groove 3 of the water-tight seal 2 with a location of the intrados face 11 of the ashlar 1, which is also accessible when the ashlar 1 is installed in the covering 110.

The injection pipes 4 preferably have a circular cross-section with an internal diameter which is preferably between 4 mm and 10 mm, for example, of 6 mm, and may be formed by respective tubes, for example, made from plastics material, which are incorporated in the ashlar 1 during the casting thereof.

Figures 3 and 3a-b show another preferred embodiment of an ashlar according to the present invention, which is

designated 1'. Identical or functionally similar elements to those of the ashlar 1 previously described are denoted with the same reference numerals, with the addition of a prime mark.

The ashlar 1' differs from the ashlar 1 previously described in that it does not have a water-tight seal along the peripheral edge 13'. In place of the water-tight seal, the ashlar 1' comprises a peripheral groove 3' which extends along the entire peripheral edge 13' and is formed directly in the body of the ashlar 1' during the step of producing the ashlar 1' itself (see Figure 3).

As Figure 3b particularly shows, the groove 3' has a cross-section which is preferably delimited by rectilinear walls, in particular a rectangular or square cross-section.

The ashlar 1' also comprises injection pipes 4' which are configured and arranged in the ashlar 1' similarly to the injection pipes 4 of the ashlar 1. In this case, each injection pipe 4' comprises a second end opening 420' in the region of the groove 3' which is formed in the peripheral edge 13' and places in fluid communication the groove 3' itself with a location of the intrados face 11' of the ashlar 1'.

Otherwise, the ashlar 1' has characteristics similar to those of the ashlar 1 previously described.

There is described below a preferred embodiment of a method according to the invention for making the covering 110 of the tunnel 100 impermeable, making reference in particular to a covering 110 which is formed by ashlars 1 according to the embodiment shown in Figures 2 and 2a-c. Unless otherwise

indicated, the following description also applies to a covering 110 which is formed by ashlar 1' according to the embodiment shown in Figures 3 and 3a-b.

After arranging the ashlar 1, the method provides for the positioning thereof in order to form the covering 110. This step can be carried out according to any method and using any equipment known for bringing about tunnel coverings which are formed by prefabricated ashlars, for example, by means of TBM in the context of the construction of natural tunnels by means of "mechanized" techniques. As already mentioned above and as is evident from Figures 1 and 4, the covering 110 is constructed by arranging the ashlar 1 so as to form a plurality of circular closed rings 111 which are beside each other in the longitudinal direction of the tunnel 100. Each ring 111 is preferably produced so as to be rotated and therefore angularly staggered in the circumferential direction of the tunnel 100 with respect to the adjacent rings 111. Figure 5 shows a portion of the covering 110 comprising two ashlar 1 which belong to two different and adjacent rings 111.

The juxtaposition of the ashlar 1 in the circumferential direction and longitudinal direction of the tunnel 100 generates in the covering 110 a grid RTG of interconnected joint lines 112, each one being defined between mutually facing sides 131 or 132 of the peripheral edges 13 of adjacent ashlar 1. As is partially evident in Figures 1 and 7, by installing the ashlar 1 according to the above-described pattern, the joint lines 112 comprise a plurality of continuous circumferential rings which are connected by a plurality of rectilinear longitudinal sections which, at least in adjacent rings 111 of ashlar 1, are angularly

staggered relative to each other in the circumferential direction of the tunnel 100.

As can be seen in Figures 8 and 9, in the region of each joint line 112, corresponding sections of the two water-tight seals 2 of a respective pair of mutually adjacent ashlar 1 are in contact with each other. The contact is brought about by means of the water-tight faces 21, more specifically by means of the water-tight portions 211 defined here, the sections of the two water-tight seals 2 involved, and causes the respective longitudinal grooves 3 formed in these water-tight faces 21 to face each other so as to form a hollow channel 113 which extends longitudinally and continuously in the region of the joint line 112 between the pair of mutually adjacent ashlar 1 in question. Therefore, the juxtaposition of the ashlar 1 in the covering 110 generally also generates therein a grid RTC of hollow interconnected channels 113, the shape of which reproduces the shape of the grid RTG of interconnected joint lines 112 described above.

As a result of the contact between the water-tight seals 2 of the adjacent ashlar 1, in the region of the joint lines 112 of the covering 110 there is generated a first sealing barrier against the introduction of water from the walls of the excavation of the tunnel 100. This barrier is potentially affected by the same disadvantages described in the introduction with reference to the coverings of tunnels of the prior art, which are connected with the incorrect contact between the water-tight seals 2 of adjacent ashlar 1.

The impermeabilization method of the invention provides for generating an additional water-tight barrier in the region of the joint lines 112 of the covering 110 by filling the above-mentioned grid RTC of interconnected hollow channels 113 with

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a sealing material 5 which is impermeable to water and which can be injected. As shown in Figures 11a-c, the sealing material 5 is introduced into the grid RTC of the hollow channels 113 by means of injection through the injection pipes 4 which are suitably arranged in the ashlar 1, the first end openings 410 of which in the region of the intrados faces 11 of the ashlar 1 remain accessible even when they are installed in the covering 110. Once consolidated and the final operating conditions have been achieved, the injected sealing material 5 forms in the covering 110 of the tunnel 100 a continuous sealing strand which is monolithic and which extends along the entire grid RTG of the joint lines 112 between the ashlar 1. This sealing strand constitutes a second water-tight barrier which acts in synergy with the first water-tight barrier which is formed by the water-tight seals 2 of the ashlar 1, ensuring a specific water-tightness of the covering 110 with respect to introductions of water in the region of the joint lines 112 between the ashlar 1, even at locations where there is poor contact between the water-tight seals 2 of adjacent ashlar 1.

The injection of the sealing material 5 can be carried out during the construction of the tunnel 100, therefore before it is brought into operation, for example, immediately after the covering 110 is positioned, or also after the tunnel 100 is brought into operation if there are introductions of water between the water-tight seals 2 of the ashlar 1.

If the covering 110 is formed by ashlar 1' without a respective peripheral water-tight seal, bringing the ashlar 1' into operation brings the respective peripheral edges 13' directly into contact, causing the grooves 3' which are formed therein to face each other in the region of the joint lines 112 between ashlar 3' which are mutually adjacent (cf.

Figure 6). In this case, therefore, there is also formed in the covering 110 a grid RTC of interconnected hollow channels 113 which correspond to the grid RTG of joint lines 112. The filling of the grid RTC of the hollow channels 113 with the injectable sealing material 5 is carried out in this case before the tunnel 100 is brought into operation, preferably immediately after the covering 110 is positioned because the sealing material 5 here constitutes the single water-tight barrier against introductions of water through the covering 110 in the region of the joint lines 112.

Independently of the type of ashlar 1 or 1' used for constructing the covering 110, and therefore the time at which the injection of the sealing material 5 into the grid RTC of hollow interconnected channels 113 is carried out, this step of the impermeabilization method of the invention is advantageously carried out in zones.

In particular, as schematically illustrated in Figure 7, this step provides for selecting in the covering 110 an injection pipe 4I which has not yet been filled with sealing material 5 and, through the respective first end opening 410 which is freely accessible from the intrados side of the covering 110, injecting the sealing material 5 until the injection pressure reaches a predetermined maximum value. The predetermined maximum value of the injection pressure may be selected on the basis of the characteristics of the injectable sealing material 5 which is used and/or the injection means available. For example, this maximum value may be equal to approximately 10 bar. When the predetermined maximum value of the injection pressure has been reached, the injection of the sealing material 5 through the injection pipe 4I is interrupted.

At this point, there is defined in the covering 110 a propagation area A of the sealing material 5 which is injected through the injection pipe 4I, in which the injected sealing material has filled a corresponding portion of the grid RTC of interconnected hollow channels 113. The form and extent of the propagation area A indicated in Figure 7 by means of a broken line have a merely indicative value for the purposes of the present description.

The extent of the propagation area A is evaluated by verifying, for example, by means of a visual inspection, which injection pipes 4S which surround the previously used injection pipe 4I have been at least partially filled with the injected sealing material. The injection pipes 4S surrounding the previously used injection pipe 4I are then advantageously used as "spy pipes" for verifying which sections of the grid RTC of interconnected hollow channels 113 have been reached and filled by the sealing material 5 which is injected through the injection pipe 4I.

Subsequently, the injection of the sealing material 5 is resumed in the region of a new injection pipe 4 which is outside propagation areas of sealing material 5 previously defined.

The above-described steps are repeated iteratively until the entire extent of the covering 110 is covered or the grid RTC of interconnected hollow channels 113 is covered.

Preferably, there are considered as the sealing material 5 which is impermeable to water to be injected into the grid RTC of interconnected hollow channels 113 synthetic resins, in particular polyurethane resins or silicone resins, single-

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component or double-component, preferably cold-polymerizable, having a high modulus of elasticity after the polymerization.

Figure 12 shows a schematic cross-sectioned view similar to the view of Figure 9 of two prefabricated ashlar 1, 1'' which are beside each other, wherein the ashlar 1'' on the left constitutes an alternative embodiment of the ashlar 1 described with reference to Figure 2. Identical or functionally similar elements to those of the ashlar 1 previously described are denoted with the same reference numerals but provided with two prime marks.

The ashlar 1'' differs from the previously described ashlar 1 in that the groove 3'' which is formed in the water-tight face 21'' of the peripheral water-tight seal 2'' comprises a diaphragm 33'' which delimits a closed chamber 34'', which extends longitudinally in the groove 3'' and which comprises the second end opening 420'' of the injection pipes 4'' of the ashlar 1''. The diaphragm 33'' can be formed in one piece with the water-tight seal 2'' or can be fixed thereto by means of any suitable method, such as, for example, adhesive bonding or thermal welding.

Otherwise, the ashlar 1'' has characteristics similar to those of the ashlar 1 previously described.

When, according to the impermeabilization method of the invention, the sealing material 5 is injected into the groove 3'' of the peripheral water-tight seal 2'' of the ashlar 1'' through one of the injection pipes 4'' of the ashlar 1'', the injection pressure causes an eversion of the diaphragm 33' outside the groove 3'' of the water-tight seal 2'' of the ashlar 1'' and inside the groove 3 facing it of the water-tight seal 2 of an adjacent ashlar 1. By suitably selecting

the form, the wall thickness and where applicable also the material of the diaphragm 33', it is possible to act so that, with a gradual increase of the sealing material 5 which is injected into the closed chamber 34'', the diaphragm 33'' stretches, or inflates in the manner of a balloon, until adhering to the internal walls of the facing groove 3. In this manner, at least along a portion of the perimeter of the hollow channel 113 which is defined by the two mutually facing grooves 3 and 3'', wherein there are present interfaces between the water-tight seals 2 and 2'', the injected sealing material 5 is surrounded by an additional layer which prevents possible losses thereof in the region of the interfaces, which losses could occur as a result of imprecise alignment in the radial direction of the tunnel covering 110 of the water-tight faces of the water-tight seals 2, 2'' which are mutually in contact.

Figure 13 is a schematic cross-sectioned view of two prefabricated ashlar 1, 1' which are beside each other, wherein the ashlar 1' on the left constitutes a variant of the embodiment of the previously described ashlar 1' with reference to Figure 3. Identical or functionally similar elements to those of the previously described ashlar 1' are denoted with the same reference numerals.

According to this variant, the ashlar 1' further comprises a peripheral tubular element 6' which is made from elastomer material and which is received in the peripheral groove 3' which is formed directly in the peripheral edge 13' of the ashlar 1'. The second end openings 420' of the injection pipes 4' of the ashlar 1' are in this case connected in a water-tight manner to the tubular element 6' and open therein.

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Otherwise, the ashlar 1' has characteristics similar to those of the ashlar 1' previously described with reference to Figures 3, 3a-b. In this case, the sealing material 5 which, according to the impermeabilization method of the invention, is injected through one of the injection pipes 4' of the ashlar 1', reaches inside the tubular element 6', filling it progressively and bringing about the dilation thereof in the manner of an air chamber inside the hollow channel 113 which is defined by the two mutually facing grooves 3' of the adjacent ashlars 1'. By suitably selecting the wall thickness and the elastomer material of the tubular element 6', it is possible to act so that, with a gradual increase in the volume of the sealing material 5 which is injected therein, it dilates until substantially completely filling the hollow channel 113. The sealing material 5 which is injected into the channel 113 is therefore also in this case surrounded by an additional layer which prevents losses thereof in the region of the joint lines between the adjacent ashlars 1'.

A person skilled in the art may apply modifications and variants to the previously described embodiments of the method for impermeabilizing a tunnel covering and the prefabricated ashlar which can be used in this method in order to comply with specific and contingent application requirements, which modifications and variants are still included within the scope of protection as defined by the appended claims.

In particular, the covering 110 of the tunnel 100 can be formed by ashlars 1, 1' or 1'' of a single type between the ones described above or also by a suitable combination of ashlars 1, 1' and/or 1'' of different types.

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The ashlar 1, 1' and/or 1'' which form the covering 110 can all have the same number of injection pipes 4, 4' or 4'' or a different number of injection pipes 4, 4' or 4''. Some of the ashlar 1, 1' or 1'' could also not have any injection pipes 4, 4' or 4''. Furthermore, the injection pipes 4, 4' or 4'' could have a branched structure comprising a single first end opening 410, 410' or 410'' in the region of the intrados face 11, 11' or 11'' of the respective ashlar 1, 1' or 1'' and two or more second openings 420, 420', 420'' in the region of the peripheral grooves 3, 3' or 3''.

The ashlar 1, 1' or 1'' with a great thickness can provide two or more peripheral grooves 3, 3' or 3'' which develop along the respective peripheral edge 13, 13' or 13'' parallel with each other at different heights. In this case, for each of the peripheral grooves 3, 3' or 3'', there may advantageously be provided at least one injection pipe 4, 4' or 4'' for each of the peripheral grooves 3, 3' or 3'' present.

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PATENT CLAIMS

1. A method for impermeabilizing a tunnel covering (110) which is formed by prefabricated ashlar (1; 1'; 1''), comprising the steps of:

a) providing a plurality of prefabricated ashlar (1; 1'; 1''), wherein each prefabricated ashlar (1; 1'; 1'') comprises an intrados face (11; 11'; 11''), an opposite extrados face (12; 12'; 12'') with respect to the intrados face (11; 11'; 11''), a peripheral edge (13; 13'; 13'') which connects the intrados face (11; 11'; 11'') and the extrados face (12; 12'; 12'') and a peripheral groove (3; 3'; 3'') which extends longitudinally in a continuous manner over the peripheral edge (13; 13'; 13''), and wherein at least some prefabricated ashlar (1; 1'; 1'') further comprise at least one injection pipe (4; 4'; 4'') having a first end opening (410; 410'; 410'') in the region of the intrados face (11; 11'; 11'') and at least one second end opening (420; 420'; 420'') in the region of the peripheral groove (3; 3'; 3'');

b) positioning the plurality of prefabricated ashlar (1; 1'; 1'') along walls of a tunnel (100) so as to form a tunnel covering (110), wherein the tunnel covering (110) comprises a grid (RTG) of interconnected joint lines (112), each one being defined between two respective, mutually adjacent prefabricated ashlar (1; 1'; 1''), wherein in the region of each joint line (112) corresponding sections of the peripheral grooves (3; 3'; 3'') of the two mutually adjacent prefabricated ashlar (1; 1'; 1'') are mutually facing so as to form a respective hollow channel (113), with which there is formed in the tunnel covering (110) a grid (RTC) of interconnected hollow channels (113) corresponding to the grid (RTG) of interconnected joint lines (112), and

c) filling the grid (RTC) of interconnected hollow channels (113) with a sealing material (5) which is impermeable to

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water and which can be injected, wherein the sealing material (5) is injected into the grid (RTC) of interconnected hollow channels (113) through the first end opening (410; 410'; 410'') of the at least one injection pipe (4; 4'; 4'') of one or more of the prefabricated ashlar (1; 1'; 1'') which are provided with at least one injection pipe (4; 4'; 4'').

2. A method according to claim 1, wherein each prefabricated ashlar (1; 1'') further comprises a peripheral water-tight seal (2; 2'') which extends along the peripheral edge (13; 13'') and which has a water-tight face (21; 21'') which is intended to come into contact with corresponding water-tight faces (21; 21'') of peripheral water-tight seals (2; 2'') of adjacent prefabricated ashlars (1; 1'') in the tunnel covering (110), and wherein the peripheral groove (3; 3'') is formed in the water-tight face (21; 21'') of the water-tight seal (2; 2'').

3. A method according to claim 2, wherein the peripheral groove (3'') comprises a diaphragm (33') which delimits a closed chamber (34'') which extends longitudinally in the peripheral groove (3'') and which comprises the at least one second end opening (420'') of the at least one injection pipe (4'') and wherein, in the step c) of filling, the injection of the sealing material (5) brings about an eversion of the diaphragm (33') outside the peripheral groove (3'') and inside the peripheral groove (3; 3'; 3'') facing it of an adjacent prefabricated ashlar (1; 1'; 1'').

4. A method according to claim 1, wherein the peripheral groove (3') is formed in one piece with the peripheral edge (13').

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5. A method according to claim 4, wherein at least some prefabricated ashlar (1') further comprise a peripheral tubular element (6') which is made from elastomer material and which is received in the peripheral groove (3'), wherein the at least one second end opening (420') of the at least one injection pipe (4') opens into the tubular element (6'), and wherein, in the step c) of filling, the sealing material (5) is injected in the tubular element (6'), bringing about the expansion of the tubular element (6') inside the hollow channels (113) which are formed by the peripheral groove (3') and by corresponding peripheral grooves (3') which face it of adjacent prefabricated ashlars (1').

6. A method according to any one of the preceding claims, wherein the step c) of filling the grid (RTC) of interconnected hollow channels (113) comprises:

c1) injecting the sealing material (5) through an injection pipe (4I) of one of the prefabricated ashlars (1; 1'; 1'') which are provided with at least one injection pipe (4; 4'; 4'') until the injection pressure reaches a maximum predetermined value;

c2) interrupting the injection;

c3) defining a propagation area (A) of the sealing material (5), in which the sealing material (5) which is injected has filled a corresponding portion of the grid (RTC) of interconnected hollow channels (113), verifying which injection pipes (4S) which surround the injection pipe (4I) which is previously used have been at least partially filled with the injected sealing material (5);

c4) resuming the injection of the sealing material (5) in the region of another injection pipe (4; 4'; 4'') of one of the prefabricated ashlars (1; 1'; 1'') which are provided with at least one injection pipe (4; 4'; 4'') which is located

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outside previously defined propagation areas (A) of sealing material (5);

c5) repeating the steps from c1) to c4) for the entire extent of the tunnel covering (110).

7. A method according to any one of the preceding claims, wherein the step b) of positioning the prefabricated ashlar (1; 1'; 1'') comprises arranging the prefabricated ashlar (1; 1'; 1'') so as to form a plurality of rings (111) of prefabricated ashlar which are beside each other in a longitudinal direction of the tunnel (100), wherein each ring (111) is angularly staggered in a circumferential direction of the tunnel (100) with respect to the adjacent rings (111), as a result of which the grid (RTG) of interconnected joint lines (122) and the grid (RTC) of interconnected hollow channels (113) comprise a plurality of continuous circumferential rings which are connected by a plurality of longitudinal rectilinear sections which, at least in mutually adjacent rings (111) of prefabricated ashlar, are angularly staggered relative to each other in the circumferential direction of the tunnel (100).

8. A method according to any one of the preceding claims, wherein the sealing material (5) which is impermeable to water and which can be injected is a synthetic resin, preferably a polyurethane resin or a silicone resin, having a high modulus of elasticity after polymerization.

9. A prefabricated ashlar (1; 1'; 1'') for a tunnel covering (110), comprising an intrados face (11; 11'; 11''), an opposite extrados face (12; 12'; 12'') with respect to the intrados face (11; 11'; 11''), a peripheral edge (13; 13'; 13'') which connects the intrados face (11; 11'; 11'') and the extrados face (12; 12'; 12''), a peripheral groove (3;

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3'; 3'') which extends longitudinally and continuously along the peripheral edge (13; 13'; 13'') and at least one injection pipe (4; 4'; 4'') having a first end opening (410; 410'; 410'') in the region of the intrados face (11; 11'; 11'') and at least one second end opening (420; 420'; 420'') in the region of the peripheral groove (3; 3'; 3'').

10. A prefabricated ashlar (1; 1'; 1'') according to claim 9, comprising at least one injection pipe (4; 4'; 4'') for each side forming the peripheral edge (13; 13'; 13'').

11. A prefabricated ashlar (1; 1'') according to claim 9 or 10, further comprising a peripheral water-tight seal (2; 2'') which extends along the peripheral edge (13; 13'') and which has a water-tight face (21; 21'') which is intended to come into contact with corresponding water-tight faces (21; 21'') of peripheral water-tight seals (2; 2'') of adjacent prefabricated ashlars (1; 1'') in the tunnel covering (110), wherein the peripheral groove (3; 3'') is formed in the water-tight face (21; 21'') of the peripheral water-tight seal (2; 2'').

12. A prefabricated ashlar (1'') according to claim 11, wherein the peripheral groove (3'') comprises a diaphragm (33'') which delimits a closed chamber (34'') which extends longitudinally in the peripheral groove (3'') and which comprises the at least one second end opening (420'') of the at least one injection pipe (4'').

13. A prefabricated ashlar (1') according to claim 9 or 10, wherein the peripheral groove (3') is formed in one piece with the peripheral edge (13').

14. A prefabricated ashlar (1') according to claim 13, further comprising a peripheral tubular element (6') which is made from elastomer material and which is received in the peripheral groove (3'), wherein the at least one second end opening (420') of the at least one injection pipe (4') opens into the tubular element (6').

15. A tunnel (100) comprising a covering (110) which is constructed by means of prefabricated ashlars (1; 1'; 1''), wherein the covering (110) is made impermeable by means of the method according to any one of claims 1 to 8.